# A Systems-Theoretic Approach to the Problem of the Responsibility of Science

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Man kann die wissenschaftliche Tätigkeit so betrachten, daß sie von einem "wissenschaftlichen System" (WS) ausgeführt wird, welches zugleich offen und adaptiv ist und dessen allgemeines Ziel darin besteht, objektives Wissen zu produzieren und zu verbreiten. WS nimmt aus seiner Umgebung Eingaben von "Nachfrage", "Unterstützung", "Ablehnung" entgegen und reagiert auf kreative Art und Weise darauf. Sein Funktionieren ist bedingt durch die Verträglichkeit seines Ziels mit denjenigen aller andern sozialen Subsysteme, die eine Maximierung der internen Variablen von WS ausschließen mögen, um das gesamte soziale System zu optimieren. Dies ist nichts anderes als ein systemtheoretischer Ausdruck für den Begriff der Verantwortung der Wissenschaft: er ist nicht streng ethisch, aber schließt die Erwägung ethischer Normen des ganzen sozialen Systems mit ein.

## THE DEBATE ON THE NEUTRALITY OF SCIENCE

It is well known that a long controversy has taken place during the last few years about the so-called "neutrality of science". In spite of its very articulated development it would be hardly possible to say that this controversy has led to any clarification of this issue, owing to the fact that the opposite viewpoints adopted by the discussants were affected by a lack of precision and quite often by a considerable amount of one-sidedness. As a matter of fact, those who advocated that science is and must be "neutral" were explicitly or implicitly convinced that science is completely reducible to a great system of exact knowledge and that the only licit aim in promoting science is therefore that of making such a knowledge more and more rich and exact. In such a perspective, no "external" factor should be allowed to interfere with this intrinsic dynamics of science, for this only could lead to an alteration of its purity and it would destroy any reliability of the scientific knowledge at all. At most, it could be admitted that the interest in "applications" could provide external occasions for fostering and stimulating scientific research, for securing to this research funds and political or institutional supports. However, it was understood that such external conditions should never become "conditionings", in the sense that they never should determine what is "scientifically valuable", "scientifically interesting", let alone "scientifically true". As a consequence of this way of thinking, the task of the scientist, but even his intellectual preoccupation "as a scientist" were considered as terminating with the discovery of some new phenomenon, with the proof of some new theorem, with the creation of some useful model, with the elaboration of some satisfactory theory, and so on. Of course, these people were by no means unaware that this exact scientific knowledge may and in fact is quite often "used" in a rich display of

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applications that are extremely dangerous to mankind, and they were also conscious that a not negligible lot of the scientific research is performed nowadays just "in view" of such dangerous applications. Yet, they maintained that all these "intentions" and "uses" of science are something which comes, so to speak, "before" and "after" the domain of scientific activity proper, so that it would be inappropriate and even detrimental for science to let them enter this domain and affect the trends and the ways of doing scientific research. In this view, science as such, and the scientists as a professional group, cannot bear any responsibility regarding the purposes and uses which "other" agencies might have in mind about science. Their own correct purpose should be only that of freely inquiring into the realm of the still unknown in order to increase the treasure of man's knowledge.

Against this presentation of science as a kind of shrine of the truth, and of the scientists as priests of this goddess, quite a different picture was drawn by those people who were especially impressed by exactly those aspects of negative application of science which we have just mentioned above. Laying stress on this, they claimed that the idealized picture of science as an uncommitted research of truth, so long predominating in the European tradition, was not only false in itself, but even a kind of mystification, consciously promoted by those social forces and classes that do everyday manipulate science for their own profit, but at the same time try to deceive people by masking their indecent practice behind the respectful and prestigious screen of "neutral" science. Up to this point one could say that this criticism amounts to maintaining that at least the largest part of the scientific research actually performed does not proceed from the noble purpose of knowing truth, but rather obeys the force of several egoistic and even evil designs. Yet one could still believe that this bad "orientation" does not deprive science of its specific quality of being a system of true knowledge (independently of its bad "use"). But even this minimal positive mark was quickly denied to science: many claimed that science is to such an extent a servant of the power, that the manipulation of truth (which is one of the means normally adopted by power) not only does not refrain from affecting "scientific" truth in particular, but science is also used with no scruple as one of the most effective tools for leading people to believe false assertions. Altogether science was deprived of any intrinsic reliability and presented as an almost totally negative instrument created by those who hold the power in order to dominate people and make their own profit.

If we consider these opposite pictures, it is not difficult to recognize that each one of them is right to a certain extent and is wrong for the rest. Or, to be more precise, each is right for what it affirms, but is wrong for what it denies. Indeed, those who stress the fact that science is a genuine research of truth and that its most specific result is the constitution of a system of more and more reliable knowledge, are certainly right in what they say; but they begin to become wrong when they deny that science is *also* something else. In particular, they seem unable to give the necessary importance to the fact that science is also one among the different human *activities* and this implies a large

spectrum of committments of an individual and of a collective nature. The consideration of this fact leads one to recognize, first of all, that the purpose that actually push our "doing science", no less than the uses which are made of the scientific discoveries, are by no means "alien" to science as such, for every human *action* cannot by adequately understood without taking into consideration the intentions and the consequences related to it. Secondly, one must also became aware that, owing to this "practical" side, science is necessarily submitted to all sorts of conditionings that affect human praxis and that they may even determine actual dangers for the fulfilment of the primary and specific "internal" goal of science, i.e. the severe research of truth.
If we now turn to the other picture, we can remark that its right points are represented exactly by the analysis of all the very complex conditions which surround the extremely varied world of pure and applied science, with the inextricable net of financial, political, social, motivational connections that envelop it and which seem to destroy any pretention of independence of science from this environment. Yet this picture is wrong when it denies that, in spite of all this intricated net, science *must* be able, and is also actually able to a considerable extent, to safeguard its intrinsic specific core, which is the effort of establishing a system of reliable knowledge. One may also say that, if science were unable to secure this standard of knowledge, the "power" would immedately dismiss any interest in it: even in order to be used as an instrument, science must keep an essential measure of self-identity and autonomy.

We could conclude this brief confrontation by saying that science is and must be both "neutral" and "non-neutral", according to the aspect of it we take into consideration. It can and must be neutral as far as it is a system of reliable knowledge; it cannot and must not be neutral as far as it is a human activity implicated with all the other aspects of the human praxis. All this may be rather clear, and is certainly very important to recognize, but new problems arise at this point. According to the two one-sided positions considered above, a kind of struggle was envisaged between science on the one side and the whole of its "external" environment on the other. For the ones the problem was that of preserving at all price the integrity of science, its independence and freedom towards the outside while for the others the problem was that of eliminating this arrogant pretension by reducing science to the dismasked role of being just a pawn in the complex game of the socio-political battle. What is common to both positions is the antagonistic way they envisage the relationship between science and the extra-scientific world. But we must note that this antagonistic way of thinking is by no means automatically eliminated once we become aware that science is somehow two different things at the same time, i.e. a system of knowledge and a human activity. For the problem immediately arises how to relate these two aspects of science. In other words, it is always possible (and we see it often in the current discussions on this issue) that one gives the predominance to the first aspect in a kind of absolute way and is led to underestimate the other or to give it the right of playing a role only "after" the first has been fully satisfied. On the other hand, there are people (and they

are perhaps the majority nowadays) which lay all the stress on the ethical, social, political, environmental aspects of the context in which science is actually embedded and are ready to compress the autonomy of science almost completely, conceiving it as a pure instrument to be totally submitted to the above mentioned exigencies.

A way out of this unsatisfactory situation may be looked for along more than one path. We believe that one of the most fruitful of such paths may be that of a systems-theoretic approach to the whole question, for it enables us to overstep immediately the very core of the difficulty, that is the antagonistic view mentioned above: we shall try therefore to outline such an approach here.

## SCIENCE AS AN OPEN ADAPTIVE SOCIAL SYSTEM

The first step of our analysis will consist in a systems-theoretic determination of the idea expressed above, according to which science is to be considered also as a "human activity". This claim implicitly includes (at least) two equally legitimated lines of development, depending on whether we focus our attention on science as the activity of an individual or as a collective or social activity. Let us remark that a system-theoretic treatment would be possible and profitable also in the case of science being considered as an individual activity. However the already outlined discussion on the so-called "neutrality of science" proves that the most urgent questions concerning the problem of the responsibility of science rise when science is considered as one of the most impressive and influencial social activities. This is why we shall limit our reflections to this second aspect. Under this point of view, scientific activity may be conceived of as a system of behaviours and actions embedded in a certain environment , being submitted to the influence of this environment and at the same time reacting to this influence and influencing the environment in its turn. This is a very simple and quite familiar picture when one thinks in terms of systems; yet in its apparent simplicity it contains a couple of consequences which are not trivial at all and which may need a rather detailed inquiry in order to show all their implications: the first is that the whole of the scientific activity constitutes a *system of actions* (and this according to systems theory means already a lot of things); the second is that, as far as we will succeed in interpreting scientific activity as a system, we will no longer be able to consider it as going on in a vacuum, but we are obliged to see it as surrounded by several *environments* (physical, biological, social, psychological, political, religious, ideological, etc.) Of course, this again seems trivial, but it will no longer appear trivial when we shall consider how this set of environments acts upon the "scientific system" and how this is to react in order to keep an acceptable and correct functioning. Moreover, an additional feature that is easily recognized is the following: such a system must be an *open* one: Indeed it is a common fact that every time we try to isolate for the sake of the analysis any social system, we are immediately obliged to consider it as being exposed to the influence coming from the other social systems with

which it happens to be actually connected: from such systems a constant stream of influences of the most different kinds flows into the investigated system and affects the conditions under which its members can act. But there is still more than that. As we have seen, those who claimed that science is totally submitted to the socio-political conditionings so that it necessarily becomes shaped and moulded by them, disregarded the fact that science is also to preserve its identity and to fight more or less successfully against the social pressure, when this risks to become a real danger for its very existence. This means that the influence of the environment is not passively received by the scientific system, which is able to *react* to the perturbations and to find the way for adapting itself to the external conditions. In the terminology of systems theory we shall designate this feature by saying that the scientific system is an *adaptive* one. Under this respect, the scientific system shares one of the most characteristic properties of the social systems in general; that of being able to give very flexible answers to its environmental conditions, by modifying its internal structures, its ways of functioning, by redefining its goals in order to go on in its essential structural characters. To sum up, the scientific system appears as an *open adaptive social system*, embedded in a variety of other systems (social and not) which constitute its environment.

## A DYNAMICAL MODEL OF THE SCIENTIFIC SYSTEM

The few elements of analysis presented thus far are certainly of interest, but we might risk to remain prisoners of a too restricted viewpoint if we were to be content with them. As a matter of fact, the first image which is suggested us by the above reflections about the relationships between the scientific system and its environment could easily be that of a struggle for equilibrium, such as it is usually considered in the case of living organisms. As a matter of fact, living systems are also considered as being open adaptive systems and their being adaptive is usually read in terms of *homeostasis*. This means that they are able to react to dangerous influences from the environment (which might lead to their destruction by altering some internal balance of their components) through the action of appropriate mechanisms which are able to restaure the balance. We know how marvellous this ability is, and how living organisms are often able to recover this balance in front of a large variety of hostile external conditions (we also know how fascinating is the cybernetic modeling of this homeostatic process provided several decades ago by Ashby). We could also go a little further and see how living organisms may be able, in front of environmental perturbations, not only to restaure the *old* equilibrium, but even to proceed toward a *new* equilibrium: it is exactly this ability which serves to explain at least some aspects of the evolution of the species according to some biological schools.

We shall not deny that such an interpretation of the interplay between the scientific system and its environment might be satisfactory in several cases. Yet we want to stress that it turns out to be insufficient in order to account for the whole of this interplay. This may be seen at once if we consider that such an

interpretation is perhaps the most faithfull way for modelling the attitude of those who believe that the task of science is to protect itself against the intrusions from the "external" environment, be it by simply repelling these intrusions, be it by "neutralizing" them so that the purity of the scientific truth would not be affected. We had already the opportunity of seeing how this attitude is one-sided, and this is already the symptom that a model based on equilibrium and homeostasis is too restricted aswell. Of course, in the history of science we have several examples of this type of reaction, which entails a kind of "closure" of the scientific system, but these are by no means the only ones, nor the most interesting for the analysis of our problem.

But which are, then, the additional points that must be still taken into consideration in order to reach a more adequate understanding of the interplay between the scientific system and its environment? The answer comes from the consideration of a fact which distinguishes rather effectively the human from the non human systems. Non-human systems, including living systems, are usually modified by the environment and they can react to this modification by *modifying themselves* again, mostly, as we have seen, in order to recover the lost equilibrium or in order to reach a new one. It is only to a very limited extent that they can modify their environment and, in any case, such a modification hardly represents a reaction to a perturbation coming from the environment. That it to say: everybody knows that the presence of living beings always induces a modification on the environment, but this happens very slowly and very seldom as a means for rendering the environment better suited to the existence of the living system concerned. But more specifically, if a perturbation from the environment suddenly occurs, the reaction of a living system is usually either that of adapting itself, or that of migrating in a more favourable environment, or to die. The reaction of human systems, on the contrary, is more commonly that of trying to *modify the environment* and this has very little to do with a search for equilibrium, be it old or new. In other words, human systems are capable of a positive, creative, innovative action upon the environment, which not only can help preserve the existing state of the system, but may also lead to conceive of a quite new way of shaping the system and of creating an environment suitable for its new envisaged way of being and functioning. This may also be expressed by saying that while several non-human systems can show a *goal-oriented behaviour* in their functioning both internal and directed toward the environment, human systems are also capable of *purposeful activity* that is, they are able to modify themselves and the environment "on purpose".

What has been said above about human systems in general (political, economic, religious, etc.), applies in particular to the scientific system, which is one of the most typical human systems. As a matter of fact, it is well known that one of the most typical marks of science is its enormous power of modification of practically all the existing environments which surround it, be they physical, cultural, social, political, and so on. This is why we shall not forget to take this important aspect into consideration in the sequel of our analysis, overstepping the too limited model of the homeostatic equilibrium.

We can certainly say that the scientific system aims at a certain stability, but we know too well nowadays that stability and equilibrium are not all the same even in physics!

## A DESCRIPTION OF SS AND ITS ENVIRONMENT

Let us now come to a closer determination of our "scientific system", which we shall denote by SS for brevity. It is customary to indicate a system as a set of variables submitted to a certain amount of reciprocal interconnections and we shall ideally do the same in the case of SS as well. Yet, we shall not try to specify such variables in this paper, as our interest is much more general here: more precisely, we are interested in examining the interplay between SS and its environment, and not in analizing the internal structure of SS itself. However, some of the variables of a system must receive a special attention, as they express, so to say, the specificity of the system, the features which enable one to distinguish it from other more or less similar systems. These variables are connected with what could be labelled as the "overall goal" of the system, or its characteristic performance, in the sense that the system would in a way no longer exist as such, if this performance should completely vanish. To give a few examples: an economic system might be characterized by the overall goal of producing commodities and/or services of a certain kind; a political system might be characterized by the ability to impose to a given society certain values with an accepted authority; and educational system might be characterized by the ability of producing the acquisition of certain notions and of certain intellectual and moral habits. As to our SS, it might be characterized by the ability to produce objective reliable knowledge about certain aspects of reality and by the possibility of distributing it in order to increase human understanding of the world and to support human praxis in it. It seems rather obvious that it is exactly this overall goal which distinguishes SS from other social systems.

We shall now try to determine the environment of SS and, as it is a particular social system, it is quite natural to conceive of it as being embedded in a "social environment" at large. Yet it is useful to refine this determination by splitting this overall environment into two parts, which we shall call "intra-social" and "extra-social" respectively. This subdivision is useful in order to make our analysis not too generic. As a matter of fact, it is very important to consider the interplay between the scientific system and other systems within a certain *given* society, and this may give rise to different specifications of the "intra-social" environment, depending on the problem which we intend to study. For example, one may analyze the position of science in a certain national society, such as Italy, Germany, USSR, USA, etc.; one may analyze science in an industrial or in an agricultural society; one may study the position of science in a capitalist or in a socialist society, etc.

It is clear that a certain SS is subject to an interplay first of all with the other systems of its intra-social environment (be they social systems as well, such as the economic, the cultural, the religious, the political system; be they non social, such as the ecological, the biological, the communicational system). But

it is no less clear that a SS is also subject, in a less direct way, to an interplay with other systems wich do not belong to its intra-social environment, but to the larger extra-social environment (which of course contains several subsystems of a social and of a non social nature of the same kind exemplified above).

We propose now to call *influence* any action from the environment which could be able to modify the state of a system. Among the influences a special attention must be paid to the *pressures*, which we shall conventionally qualify as those influences which could be able to challenge the existence of a system. These pressures usually determine *reactions*, which may be defined as behaviours of the system oriented to its own preservation. It is clear from this quite wide definition that reactions are not necessarily limited to the goal of restauring an equilibrium; this goal may be seen much better as an effort to preserve stability, which sometimes could be reached in a dynamical and dialectic way, not coinciding with the establishment of a position of equilibrium.

In order to render our intuitive analysis more suited to an exact treatment we shall now introduce the notion of *essential variable*. As we already saw above, every system is characterized by some specific global or overall goal. We propose to call essential variables those which cannot receive a value falling below a certain limit, without compromising the realisation of the overall goal of the system. As the notion of "below" is a little vague and might even suggest a too narrow relationship with a linear representation, we shall introduce the notion of *critical range* of the variables and say that the essential variables are characterized by the existence of a critical range such that their values cannot fall outside this range without compromising the stability of the system. Hence we can now make more precise the notion of reaction of a system by saying that it consists in a set of behaviours capable to maintain the values of the essential variables within their critical range. It is obvious that we can consequently qualify a pressure on the system as an action, or a set of actions, from the environment which could lead the essential variables to overstep their critical range. Let us note incidentally that a system might come to an end by purely internal reasons. In such a case we could call *tensions* those internal actions, being aware anyway that a system might come to an end also for other reasons. But this question lies outside the interest of this paper.

Coming to the specific case of SS, we can say that it possesses two essential variables: the production of objective knowledge, and the capacity of propagating this knowledge so that it could increase the human understanding of the world and support the human praxis. Every pressure that could affect SS will challenge, in the last analysis, the possibility of the sytem to keep the values of the said variables within their critical range and it is clear that the system will usually react in view of securing to these variables the permanence within their critical range. It is already intuitively clear that this process of pressures and reactions can lead to quite a lot of different situations: in some extreme cases it may happen that the pressure from the environment brings the value of the essential variables outside their critical range: then we would say that the scientific system has been destroyed, but this can happen only very

seldom and only for a limited period of time. Indeed the existence and a minimal functioning of SS, owing to the interrelationships existing between SS and the other social systems of its intra-social environment, is such that the whole intra-social environment (conceived as a system of its own) could hardly survive with no SS at all, or at least several other systems belonging to this environment would seriously suffer from a total black-out of SS. This is why the most common situation is that of a more or less reduced performance of SS, which still allows it to keep the values of its essential variables within their critical range.

A pictorial presentation of the above discourse may be found in the diagram of fig. 1. We shall now illustrate the abstract treatment given thus far by a couple of concrete examples. It will be useful for the sequel of our discussion to indicate with $v_1$ and $v_2$ the two essential variables of SS, according to the following definitions: $v_1$ will be the variable expressing the amount of "exact knowledge" produced by the system; $v_2$ will be the variable expressing the actual possibility of communicating this knowledge, making it available for cognitive and practical purposes in general.

## A CONCRETE EXAMPLE

Let us take into consideration the general situation of science within the context of the Nazi Germany. Such an intra-social environment contained among other an "ideological system" characterized by the tenet of racial discrimination, and a "political system" characterized by the use of dictatorial authority; there was also a "communicational system" deeply controlled by censorship and efficently influenced by propaganda. As a consequence of the racial discrimination, the political system came to a persecution of Jewish scientists, to which it also added a persecution of other political opposers as well, and the consequence was that many scientists were obliged to escape, or were sent to concentration camps, or were at least deprived of their job. All this resulted in a heavy pressure on SS and the elimination of so many people from the scientific practice clearly led to a diminution of the value of $v_1$ for SS. If we now consider the extra-social effect of this pressure on the German SS, we may see, e.g., that several exiled scientists went to Great Britain or to the United States, continuining there their scientific activity, which eventually led to a considerable increase of the value of $v_1$ is the SS of those countries. Another aspect of the said political pressure was the forced orientation of the whole scientific research toward military applications. The consequence was obviously the contraction of te possibilities offered to the development of certain branches of science and the extraordinary stimulation given to others, so that the value of $v_1$ decreased for the firsts and increased for the seconds. On the other hand, the wide introduction of the military secret led to a general decrease of the value of $v_2$. The combined pressure of the ideological and of the political system led several compliant scientists to elaborate, e.g., distorted scientific doctrines supporting the racist dogmas, and this resulted in a diminution of the value of $v_1$. In addition to that, the powerful Nazi

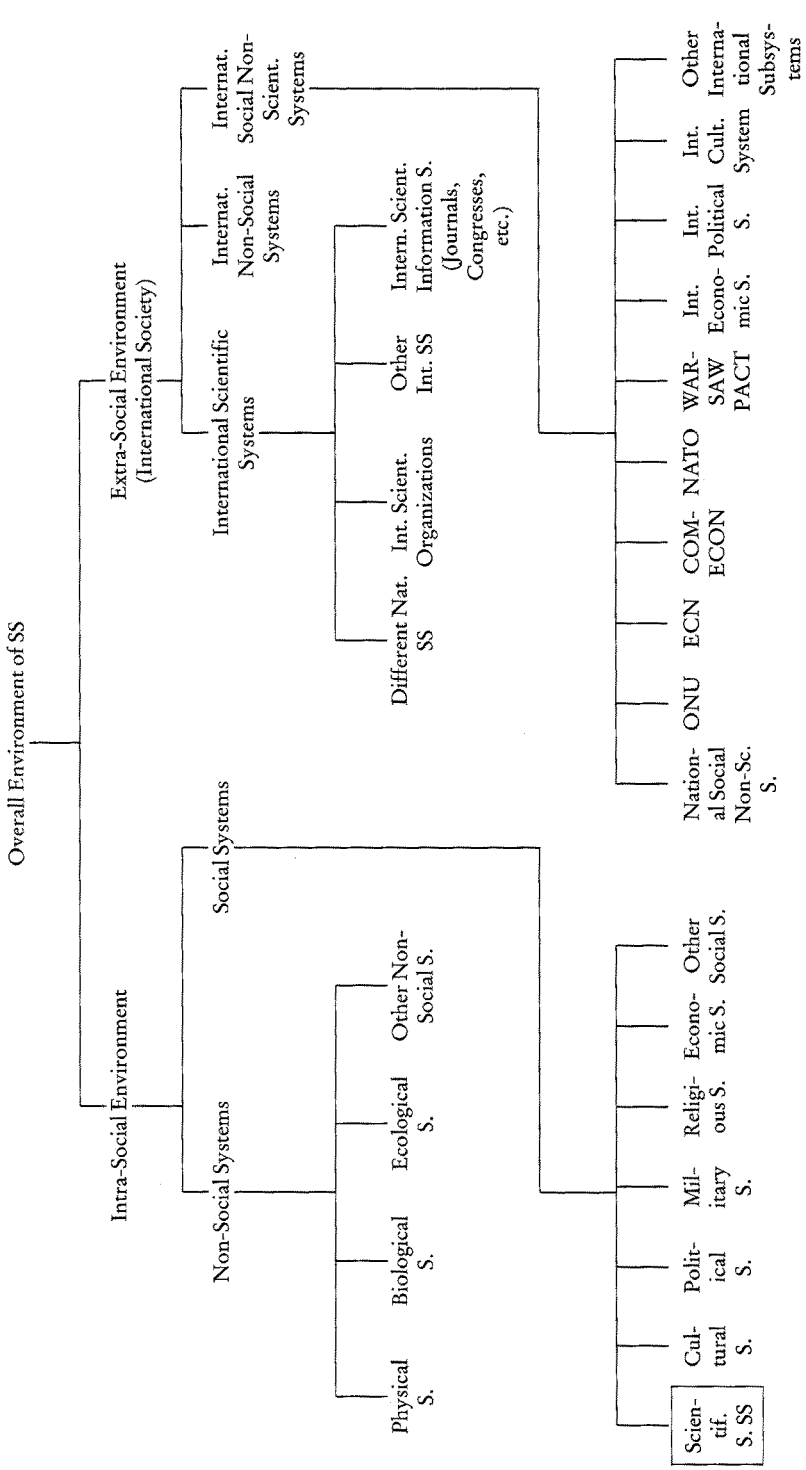


Fig. 1 – Components of the overall environment of a given scientific system SS.

propaganda was able to give a large diffusion to such distorted or even totally false doctrines, and the consequence was a diminution of the value of $v_2$ (in fact, the total volume of the "scientific information" propagated was increased, but at the expenses of the exact, objective and reliable information, which only counts in the evaluation of $v_2$).

How can in general a given SS react against such pressures coming from its intra-social environment, and in particular from the political, ideological, cultural, military systems? The most direct reaction is that of developing those sectors of science that are not forbidden or that are even stimulated by the pressure involved (e.g., applied physics or chemistry, cybernetics, etc.). Another form of reaction may consist in a continuation of the challenged branches of research at a reduced rate, or even in an underground way. Through these strategies a given SS may be able, and is usually able, to preserve the overall value of its essential variables within their critical range.

It would be not difficult to illustrate other examples, belonging both to the past and to more recent times, of pressures exerced on SS especially by different religious, ideological and political systems.

## INPUTS, OUTPUTS, AND SUMMARIZING VARIABLES. THE FEEDBACK LOOP

Let us now come back to the general treatment of our problem. The schematic discussion developed thus far should be enough convincing. Yet, although our scheme is already reduced to its essential features, it is still too complicated in view of a theoretical and, especially, of a practical treatment of the interplay between SS and its environment. As a matter of fact, the number of environmental factors capable of influencing SS (and to be influenced by it) is extremely large and if we should try to indicate by means of a variable every such factor we should very quickly be led to an impossibility of theoretically and practically controlling such a set of variables. A first step towards the simplification of our problem is that of subdividing all these possible variables into the two familiar classes of *inputs* and *outputs*; this subdivision however will not diminish their number, but simply enable us to introduce a useful distinction in their orientation, according to the fact that their flow crosses the *border* of SS toward the inside or toward the outside. In order to obtain a reduction in the number of the variables or parameters involved we may follow two different strategies: either to select a restricted number of these parameters, which we shall decide to consider as the only *relevant* ones, or to look for a kind of "conceptual synthesis" of them. The first choice would lead to a higher degree of precision, but it might well happen that the selected parameters could not cover several actual situations considered, and that some of the disregarded parameters could reveal at a certain moment a not negligible importance. The second choice is certainly more generic, but it has the advantage of leaving us much more flexibility for the treatment of the questions; on the other hand, its "genericity" will be quite compatible with the "generality" of the discourse which we are developing in this paper. But what does it mean to look for a "conceptual synthesis" of the parameters? we

shall explain it at once. Our general idea is to obtain, so to speak, a condensation of the large display of the parameters under the heading of a few *summarizing variables*, which we shall try to determine by considering which is in the last analysis the "kind of effect" that a certain parameter tends to exerce on SS (or on the environment respectively). It is therefore clear that we shall try to determine these summarizing variables in the class of the inputs and in that of the outputs.

As to the inputs, we propose to distinguish three classes of them, which we shall indicate by three summarizing indexes: the *requests* (denoted by $i_r$), the *supports* (denoted by $i_s$) and the obstacles (denoted by $i_o$). This very simple and reasonable distinction will permit us to "canalize" whatever particular influence from the environment within the one or the other of these three variables, according to the "kind of effect" which it will manifest, in conclusion towards SS. This level of analysis is certainly not very deep, but on the other hand it does not oblige us to make a preliminary choice of the "relevant" factors. Moreover, we shall be dispensed with the very complicated task of "following" the influence of every single input on the internal structure of SS, which might involve some very intricated mechanisms.

Here are a few examples. Let us consider the case of the racial discrimination presented above: it is easy to classify it as an "obstacle" to the functioning of SS, while it would be a rather complicated job to specify how exactly it could operate its negative effects by affecting individual scientists and, as a global consequence, the performance of SS as a whole. To make such an analysis, we should have at our disposal a subdivision of SS into subsystems of different kinds (e.g., the subsystem of the scientific organization, that of the affiliation of the individual scientists to the different disciplines, etc.); we should also know how a diminution of researchers within a given discipline may influence the acquisition of knowledge in this discipline and in other disciplines as well, which in turn would imply a determination of intra-systemic functions and correlations in SS, and so on.

As another example, we could imagine that the use of computers become more and more widespread within a certain society, owing to needs connected with the development of the management, of the communication system, of banking, etc. It is clear that such a developing need will directly determine an input of the type "request" toward SS, under the form of a lot of precise questions addressed to that subsystem of SS which is known as "computer science". But it is also clear that such a need will also act as an input of the type "support" for SS, inasmuch as it will stimulate research in different fields of pure and applied mathematics, in electronics, etc. Here again we can note that it would be quite complicated to follow the action of that input on the different subsystems of SS, while it may be useful to conceive it globally as constituting a form of request and/or support, for some general considerations.

As last example let us consider the interest that the religious authorities may have for some branches of research concerning matters which are believed to have important contact points with some dogmas. In this case the inputs

coming from the religious system may sometimes be expressed as supports, sometimes as obstacles toward the scientific researches involved.

As it should be clear from the above discussions, this way of envisaging the question has the advantage of dispensing us with the need of giving a detailed presentation of the *internal structure* of SS, and this is an advantage because we are interested here in considering the interplay of SS *as a whole* with its environment, and it is obvious that our task is simplified if we can by-pass the consideration of its internal structure. Of course, in case we were interested in examining some particular and specific aspect of such an interplay, we should immediately be obliged to determine such a more refined structuring of SS. The same is true if our interest were focussed on the functioning of SS, as far as it is affected by the interplay with its environment but, again, we stress that our interest here is not directly concerned with the *internal functioning* of SS.

Let us now come to the outputs. Here our task appears as happily simplified as we can take as "summarizing variables" the very *essential variables* of SS, for the overall effect of the activity of the different elements of SS may be very naturally seen as producing a certain amount of valuable knowledge and as giving to this knowledge a formulation apt to be understood by the environment and to be used by it both for theoretical and practical purposes.

However, an interesting feature is that these outputs are able to determine new inputs toward SS, according to the quite familiar circulation of feedbacks which is so common in all the social systems. In other words, scientific knowledge determines modifications in the environment and these in turn produce new inputs of request, support, or obstacle into SS. The most classical example of this is certainly represented by technological progress: the outputs from SS contribute enormously to the fostering of technology but the development of a more advanced technology determines in its turn a powerful increase in the progress of scientific research. What is so clear in the case of technology may be repeated, perhaps in a less direct way, also for other elements of the environment of SS, as it can be seen from a couple of examples of a less simple nature. Let us consider for instance the great development of nuclear research in physics: besides several consequences *within* SS, it has given rise to a very important technological *output*, represented by the construction of nuclear power stations. This fact has produced a certain amount of consequences of different kinds in several subsystems of this environment, such as the energetic system, the industrial system, the economic system, etc., and in particular has determined a certain impact on the social system owing to the existence of some serious risks of general disaster in case of uncontrollable breakdowns that might occur in the functioning of the power stations. The result has been a situation of generalized alarm and uneasiness inside the social system, which has entered a kind of conflictual tension with other subsystems (e.g., the energetic and the economic systems tend to support the construction of nuclear power stations in spite of the fears of the rest of the social community). The spreading of this output coming from SS has determined, in such a way, a wide spectrum of feedbacks on SS, which can be "canalized" according to the one or to the other of the three

"summarizing indicators" mentioned above. Some of these feedbacks may consist in requests of further research oriented toward the discovery of new means for keeping the functioning of the nuclear stations under a more satisfactory control so that the risks of their use may be totally eliminated or at least rendered extremely small (this will mean an increase of $i_r$). But the climate of generalized diffidence permeating the social community also determines a decrease of the support in favour of the nuclear science and even a certain measure of hostility against it (which will mean a decrease of $i_s$ and an increase of $i_o$). Of course, this could hardly lead to a total stopping of this research, owing to other forms of support coming from the economic, political, military systems, which will tend to counterbalance the decrease of $i_s$ determined by the widespread hostility of the social community. Moreover even this hostility will not determine a pure and simple decrease of $i_s$ regarding SS as a whole, for it actually determines other forms of $i_r$ and of $i_s$ in favour of researches capacable of promoting the production of different or "alternative" energies.

Let us briefly consider a last example. Recent developments in the biological sciences have shown that the performance of a "genetic manipulation" of man's chromosomes is already within the possibility of human praxis. When this information crossed the border of SS and became known under the form of a purely informational output to the social environment, different reactions started developing within several subsystems of it, which felt concerned with the perspective of an actual realization of the genetic manipulation on man. The cultural system, the moral system, the religious system are among those that were led to a rather direct reaction, which has usually taken the form of a more or less pronounced opposition against this form of research and we know that this feedback of the type $i_o$ has been received by some scientists with a special sensitivity, so that they decided to abandon their research in genetics.

## NEUTRALITY OF SCIENCE REVISITED

The few examples given above are enough to show how the existence of this complex feedback loop introduces into the study of SS a degree of complexity which deems to failure every pretension of adequately understanding it by taking into consideration only its internal structure, i.e. its purely "scientific" functional or relational links, such as inter-theoretic or inter-disciplinary connections and so on. The fact is that such interconnections although they are actually important and unavoidable, are not *sufficient* in order to understand the whole behaviour of SS, especially because their way of operating is subject to change as a consequence of the feedback coming from the environment under the most different forms. In other words: every important change occuring *within* SS necessarily leads to a set of outputs which affect the environment, but then we have a series of feedbacks from the environment, which in turn produce some change *within* SS itself. This consideration enables us to understand why only a dynamical model of SS may be able to account for its complex structure and functioning: this depends not only on the fact that SS undergoes modifications as a consequence of its relationship with the environment (i.e. on the fact that SS is *modified by the environment)*, but also

on the fact that a not negligible part of this modification is constituted by feedbacks which were determined by outputs from SS (i.e. SS is *modified by SS itself* through the feedback loop). This situation must be understood very clearly: we ar not claiming that the internal modifications of SS may be subdivided into two *parts*, one depending on the internal functional connections of SS, one depending on the feedbacks from the environment. The actual situation is that every single modification of SS usually depends under a certain *standpoint* or to a certain extent on the internal laws governing the functioning of SS, and under another standpoint or to a certain extent on the external feedback. This means that one is certainly entitled to *distinguish* these standpoints for the sake of the analysis, but that one cannot *separate* them, let alone pretend to understand adequately the internal evolution of SS by disregarding the one or the other.

All this may sound rather convincing at this point, but it is a consequence of the system-theoretic approach adopted here, while it might be not so easy to grasp within other approaches. Indeed we already had the opportunity of considering, at the beginning, the position of those who claim that science must be considered solely as a system of knowledge, which can undergo modifications and be subject to a certain evolution only as a consequence of cognitive facts, such as the discovery of new phenomena, the formulation of new hypotheses, the falsification of accepted theories, the discovery of counterexamples, the creation of intertheoretic relationships, and so on. This has been, in particular, the position held by the representatives of the neopositivistic movement of the analytic philosophy, of the Popperians, of the structuralists. We can say that they correctly saw and investigated only *one side* of the issue, but were wrong in pretending that this was enough to understand the whole of the phenomenon of scientific activity and especially of the internal evolution of science. On the other side, there have been people in more recent times who have almost completely disregarded the specific internal structure of science and have seen it as a result of any kind of social conditionings, of psychological motivations, of political pressures and the like. This may be said of scholars like Kuhn and Feyerabend, who are too inclined to underestimate the existence of some methodological structures and of a constant aspiration to reach exact knowledge as specific marks of scientific activity, being ready to accept a more or less pronounced anarchism in the scientific enterprise, which ultimately prevents any distinction between science and non-scientific human enterprises. The same holds true also for those who opposed the notion of the neutrality of science by claiming that science is simply an instrument in the hands of the power, completely manipulated by it and hence incapable of providing us with any reliable knowledge. Here again we can repeat that those people correctly saw and investigated *one side* of the issue, but were wrong in their pretention that this was sufficient in order to understand the whole of the scientific structure and evolution.

We could summarize the respective mistakes of the two opposite positions by saying that the first was wrong in conceiving of science as an *isolated* systems, while the second was wrong in conceiving of science as *no system*

proper, i.e. as lacking a specific unity expressible by means of a particular overall goal of its own. This by the way permits us to revisit the debated issue of the "neutrality" of science. If under such a neutrality one understands the possibility of a complete isolation of science, reduced to be enclosed in the effort of reaching its cognitive goals, we can say that such a neutrality is even theoretically impossible, for at least to a certain extent, as we saw, the *internal* dynamics of SS depends on its feedbacks from the environment. Yet there is a sense according to which we can and also must speak of a neutrality of science: this legitimate sense is expressed by the right of SS to fight in order to keep the value of its essential variables $v_1$ and $v_2$ within their critical range. However we are conscious by now that the fulfiment of this task would be frustrated if $i_r$ and $i_s$ were reduced to zero, or if $i_o$ were to become too great and this shows how even the preservation of the legitimate neutrality of science cannot be obtained without a reference to the environment of SS, that is without dismissing the idea of science as an isolated system.

It may not be superfluous to remind that the whole of our discussion depends on the explicitly stated starting point, according to which we proposed to consider science as an "activity" and, consequently, to consider SS as system of actions. This is why it is perfectly legitimate to speak of an overall *goal* of SS, or of its "fighting" for keeping its essential variables within their critical range, while this way of speaking might sound rather strange if applied to science considered as a *system of knowledge*. On the other hand, we do not dismiss at all this possible meaning of the concept of science: when we said that the overall goal of science may be identified with the aim of maximizing the value of the essential variables $v_1$ and $v_2$, we defined $v_1$ in such a way that it practically coincides with the notion of the creation of a system of exact and reliable knowledge. Hence we can say, from our viewpoint, that science as a system of knowledge constitutes one of the goals (and indeed the major one) which guide the behaviour of the members of SS, although this cannot be, for the above investigated reasons, the unique goal of them. The awareness of such a plurality of goals will permit us now to enter in a rather precise way the discussion of the debated question of the responsibility of science.

## THE QUESTION OF THE RESPONSIBILITY OF SCIENCE

According to the systems-theoretic presentation proposed in this paper the task of the members of SS may be seen as consisting of several aspects. First of all, they must elaborate the inputs coming from the environment under the summarizing parameter $i_r$ and try to provide answers capable of satisfyig these requests. By so doing they will also try to maximize the value of $i_s$, that is to say to receive the greatest possible amount of support from the environment. Parallel to this, an effort will be done to minimize the value of $i_o$, that is to say, to avoid as much as possible the creation of oppositions or obstacles from the environment against the activity of SS. All these efforts must be embedded, so to speak, into the continuous effort of reaching the overall goal of SS, that is to say of maximizing the value of the essential variables $v_1$ and $v_2$ by producing

the greatest amount of exact and reliable knowledge and by fostering the largest possible propagation of it. As is always the case when a multiplicity of goals is present, the problem is that of making them compatible or, to put it differently, to optimize the performance of SS conceived as characterized by the simultaneous presence of these goals.

The above sketched strategy in the behaviour of the members of SS may be considered and described under two different and even opposite viewpoints. According to the first, one could say: SS aims at responding to the requests of its environment by producing beneficial outputs and by looking for an increase of solid, exact, objective and reliable knowledge. As a *consequence* of this, it receives from the environment an unsollicited support and an all too natural elimination of obstacles. Any form of compression of this beneficial activity should therefore be banned and condemned.

According to the second viewpoint, one could say: SS aims at reaching its own internal goals, but in order to do that efficiently it must also produce some outputs capable of acquiring support and of eliminating opposition from the environment. It performs these tasks only on its own benefit, according to a kind of opportunistic strategy.

It is not difficult to recognize under the first way of considering science the optimistic and enthusiastic conception which characterized the cultural atmosphere of the positivistic and neopositivistic mentality, and which is frequently labelled nowadays as "scientism". According to this optimistic evaluation, science is always and only positive, while its possible negative applications or uses depend on *other* external agents. On the other hand it is no less easy to recognize under the second way of considering science the egoistic and opportunistic picture of it which was typical of the attacks promoted against science by people who tried to disclaim its neutrality and to present it as a docile instrument of the power, ready to produce whatever the power wants, independently of the dangers that this might mean for the social community.

As a matter of fact, both conceptions ar one-sided and we could express this by saying that both are wrong, but also by saying that both are right (of course, to a certain extent). The common defect of both, however, is that they keep the discussion on a sterile moralistic plane, trying to make a process to the intention of the scientists. The real situation is that all the envisaged goals are present and legitimate within the behaviour of SS, and this because the already mentioned feedback loop makes it impossible to separate them and to classify some of them as "good" and acceptable and the others as "evil" and unacceptable.

More precisely: when we stressed that SS must try to respond to the requests coming from its environment, to earn its support and to avoid its opposition, we expressed what may be considered an objective characterization of the notion of *responsibility* of science. Indeed the concept of resonsibility contains already in its etymology a reference to a "response": this is very often intended as a response to some ethical imperative (and we are not going to deny that such an interpretation makes sense in certain contexts),

but there is a less engaging and less controversial meaning of this responding, which may be captured through the systems-theoretic approach outlined here. Science has a responsibility as far as it is embedded into a social environment with which it interacts through inputs, outputs and feedbacks. On the other hand, SS has its own specific overall goal and legitimately tends to satisfy it: this implies that the entire activity of SS cannot be limited to those aspects which are directly oriented to the satisfaction of the needs and requests of the social environment; let alone that the satisfaction of these requests should lead to a distortion of its specific task of securing exact, objective and reliable knowledge.

All this may be advocated without use of moral arguments, for we have already seen how this responsibility is an intrinsic and ineliminable condition for the existence and the functioning of SS, so that we can safely say that without such an attitude of responsibility even the realization of the specific goal of SS would be frustrated. Hence this responsibility becomes part and parcel of scientific research *as such*, though in a kind of roundabout way. In the same way as we can say, for instance, that research in biology would not be possible without certain notions of a mathematical character, or without the existence of certain technical facilities, or without certain funds, we can say that it would also be impossible if it were to be totally disconnected from the favourable inputs coming from the environment and this is tantamount to saying that biological research must share its part of the responsibility of SS in order to be possible. This is true for every kind of scientific research, be it pure or applied.

## RESPONSIBILITY AS OPTIMIZATION

How could we qualify the nature of the above reasonings, if we maintain that they may dispense us with a genuine ethical way of thinking? The answer is that they express in an essential way a standpoint of *optimization*. Let us explain in which sense this claim must be understood.

Every social system, as we have seen, legitimately tends to maximize its own essential variables (corresponding to the fact that it tends to satisfy its own overall goal). But, being an open system, it cannot really do that without receiving something from its environment and giving something to this environment in exchange, which means that it cannot help interacting with the other social systems of its environment: its outputs become necessarily inputs for some other systems and vice versa. This means in particular that its outputs may act as inputs of the kinds $i_r$, $i_s$, or $i_o$ with respect to some other social system and in such a way become sometimes promotional and sometimes detrimental to this system. In the second hypothesis, the social system concerned might find obstacles in the protection of its own essential variables. To give an easy example, let us imagine that a certain request for funds comes from SS and is addressed to the political system. In deciding the allocation of these funds the political system has to introduce some cuts in the funds available, let us say, for the social security. In such a case the request of SS might challege the fulfilment of the goals of the social security system and this

might react against such a request. How can the problem be solved? Of course no solution would be possible if SS could not give satisfactory responses to other needs (requests) of the environment, so that the sacrifice in the allocation for social security could be somehow "compensated" elsewhere. However it is certain that the allocation of funds for SS never could have as a consequence such a contraction of funds for social security, which would prevent it from keeping the value of its essential variables within their critical range. But this discourse holds true also as regards SS: no social need should be such as to subtract from SS such an amount of funding as to make it impossible to it to keep the value of its essential variables within their critical range, and this because, as we have seen, the existence and the functioning of SS is vital to the existence of the whole social system owing to the complex net of inputs, outputs and feedbacks which exist between SS and the entire environment. Only on some very exceptional and dramatic circumstances (and for a limited time) can a certain social system be reduced to inactivity.

This brief discussion shows us a quite familiar feature: whenever several systems are interconnected in such a way that they are at the same time subsystems of a larger overall system, we are confronted with a problem of optimization. Every single system has a natural tendency to maximize its own essential variables, but such a maximization is incompatible with the satisfactory functioning of other subsystems, and hence with a satisfactory functioning of the general or overall system itself. Hence the problem is that of "optimizing" the entire system of essential variables, so that no one should be obliged to overstep its critical range and at the same time the overall goal of the great overall system could be satisfactorily attained.

One might say that such a respect for the exigencies of the other systems is a moral obligation for the members of SS (and of other systems as well), but this is not correct. Of course, members of SS *may* feel this *also* as a moral obligation, but this is not *necessarily* the case, for if it is true that SS has so to speak the "duty" of respecting the exigencies of other systems, it is no less true that this corresponds also to its own "interest", owing to the already discussed reasons.

## THE PROPER PLACE OF ETHICS IN THIS PROBLEM

From the above discussion one might have the impression that we are firmly decided to eliminate any kind of moral consideration from the problem of the responsibility of science. This impression is false: we are convinced that the problem of the responsibility of science has to do with ethics, but we want to specify how this may be correctly understood and our systems-theoretic approach will help us again.

We have seen that among the systems constituting the social environment of SS there are, e.g., the cultural, the ideological, the philosophical, the religious and also the ethical system. On the basis of the entire discussion developed in this paper we are now obliged to say that SS must take into consideration also the exigencies of these other systems, and this not on some ethical grounds, but simply on systems-theoretic grounds. We could say: it is not because of an

ethical reason, but because of a system-theoretic reason that SS must take into account also the ethical imperatives. Should it disregard these, the consequence would be a decrease of support or even the creation of oppositions from its environment. On the other hand, this cannot imply that the ethical system is endowed with the right of censorship or of supervision as regards SS: this simply means that the relations between these two systems must undergo that process of optimization which is valid in general, and this may become more and more clear if we stop considering, as one is so frequently tempted to do, both systems as "closed".

Indeed, it is not only theoretically apparent from our previous discussion, but is also supported by a great deal of investigation in the domain of history of science and history of cultures, that the evolution of science has always been deeply influenced by the existing philosophical, metaphysical and ethical doctrines, no less than by the existing state of development of technology and economical structure. But the reverse is equally true: the development of science has deeply influenced philosophy, metaphysics and ethics. Hence there is no position of "domination" of one domain upon the other, but rather that situation of reciprocal feedback which we have considered as being a general feature of the interplay between all the social systems. In this sense it is equally vital for a given society to develop a science compatible with its ethical standards, as well as to develop an ethics proportionated with its scientific achievements. In this sense ethics too must be conceived as subject to a dynamical evolution, depending on a great deal of internal and external factors, among which the inputs and feedbacks coming from SS certainly play and legitimately play a considerable role. Of course, this cannot mean that ethics must be dependent on society, politics, religion, ideology, and science completely: the ethical system has its specific features as well and is entitled to preserve its identity, that is to say to safeguard its essential variables, which might be identified, perhaps, as the task of determining some general imperatives to serve as guidelines for human behaviour. The correct position consists in recognizing the legitimacy of these ethical exigencies and to harmonize them with those of the other social systems.

The advantage of this approach is to avoid the difficult and perhaps ill posed question of the "hierarchy of values", which would oblige us to determine once for all whether the value "truth" (which is in a way specific of science) may be considered as inferior to "usefulness", to "beauty", to "charity", to "social progress", to "political freedom", etc. Within a systems-theoretic approach we can see that all these, and other, values have an intrinsic dignity and legitimacy and that the real problem is not that of establishing a scale of prevalence among them, but rather to secure to each of them an adequate rate of development, by optimizing in a dynamical way their complex interrelationship.

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